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Breeding Plan to Preserve the Genetic Variability of the Kootenai River White Sturgeon

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EXECUTIVE SUMMARY

Natural reproduction in the Kootenai River white sturgeon population has not produced a successful year class since 1974, resulting in a declining broodstock and 20 consecutive year classes missing from the age-class structure. This report describes a captive breeding plan designed to preserve the remaining genetic variability and to begin rebuilding the natural age class structure.

The captive breeding prograrn will use 3-9 females and an equal number of males captured from the Kootenai River each spring. Fish will be spawned in pairs or in diallel mating designs to produce individual families that will be reared separately to maintain family identity. Fish will be marked to identify family and year class before return to the river. Fish should be returned to the river as fall fingerlings to minimize potential adaptation to the hatchery environment. Initially, while tagging methods are tested to ensure positive identification after return to the river, it may be necessary to plant fish as spring yearlings. Number of fish planted will be equalized at 5,000 per family if fall fingerlings or 1,000 per family if spring yearlings. Assuming annual survival rates of 20% during the first winter for fall fingerling plants and 50% for years l-3, and 85% for years 4-20 of all fish planted, the target numbers would yield 7.9 progeny per family or about 4 breeding pairs at age 20. Natural survival in the river environment during the 19+ years from planting to maturity would result in variability in genetic contribution of families to the next broodstock generation. Fish planted per family would be adjusted in future years when actual survival rate information is known. Broodfish will be tagged when captured to minimize multiple spawning of the same fish.

Implementation of this breeding plan each year for the 20-year generation interval, using 5 different mating pairs each year, will yield an effective population size of 200, or 22.5% of the estimated 1990 population. Because this captive breeding program is designed to produce approximately 8 breeding adults per family and to approximate a "normal expanding" natural population, it should not exaggerate the contribution of a small fraction of the parent population, as occurs in typical supplementation programs. This captive breeding plan should be discontinued once habitat is re-established to permit successful natural spawning and recruitment in the Kootenai River.

Breeding Plan to Preserve the Genetic Variability of the Kootenai River White Sturgeon

INTRODUCTION

The Kootenai River white sturgeon (Acipenser transmontanus) is a closed population residing in the Kootenai River between Kootenai Falls (50 km below Libby Dam) and Bonnington Falls (Corra Linn Dam). This population has been isolated from other Columbia River white sturgeon stocks for approximately 10,000 years (Northcote 1973). Estimates by Partridge (1983) and Apperson and Anders (1990) show the number of fish in the population declined from 1,148 in 1982 to 880 in 1990, a reduction of 27% in only 8 years. Fish numbers declined because reproduction and recruitment have been unsuccessful since 1974 (Apperson and Anders 1990, 1991). The threat of further decline in fish number and loss of genetic variability led local conservation groups to petition the U.S. Fish and Wildlife Service in June 1992 to list the Kootenai River white sturgeon as an endangered population under the Endangered Species Act of 1973 (Duke 1993).

Several steps have been taken to protect the Kootenai River white sturgeon. Fishing restrictions were imposed in Montana (fishery closed in 1979), Idaho (fishing limited to catch and release in 1984), and British Columbia (fishing limited to catch and release in 1984) to limit further losses. The Kootenai River White Sturgeon Committee, with representation from federal and state agencies, the Kootenai Tribe, and public interest groups, was formed in 1992 to undertake efforts to increase flow rate and restore natural river habitat. Efforts by management agencies to restore the habitat needed for sturgeon spawning and recruitment have yielded little progress to date. Until the habitat is restored, a systematic program to preserve the genetic diversity of this population should be implemented because natural aging processes (mortality and senility) and poaching will continue to reduce the population each year until it approaches extinction.

Natural reproduction has failed in this population for the past 19 years or the equivalent of one full generation. As a result, the natural age structure has been seriously disrupted and the effective population size reduced. Management agencies currently think that reproductive failure occurs because (1) adults fail to spawn due to lack of sufficient water flow to allow successful natural spawning (Apperson and Anders 1990, 1991), and (2) progeny fail to survive to the yearling stage due to lack of food supply, toxic contamination, or dewatering of nursery areas (Apperson and Anders 1990; Don Scaar, Montana Department of Fish, Wildlife, and Parks, personal communication). Flows in the Kootenai River from June to October have been much lower than historic flows since completion of Libby Dam in 1972. Spawning success would be affected if May-June flows are inadequate to attract mature fish to spawning areas or to support successful spawning. Low flows from July to September would also contribute to reduced larval survival by dewatering significant parts of the shallow larval feeding areas.

In the absence of natural reproduction and restoration of natural spawning conditions, a genetic preservation program must be initiated that includes limited culture. The wild adults remaining in the population must be spawned for an entire generation of year classes before these fish are irretrievably lost, if the existing genetic variability is to be preserved and a natural age structure re-established. The proposed program would capture wild fish, collect gametes, and produce the essential new generation. Progeny would be reared through the vulnerable juvenile stages (incubation, sac-fry, initial feeding fry, and fingerling stages) as separate families using procedures described by Conte (1988). Fish would be returned to the Kootenai River at the earliest life stage at which they could be recruited successfully and survive to maturity. The potential hazards of using captive culture (inbreeding, genetic drift, domestication, selection, behavioral conditioning, and exposure to disease) and the negative interactions of hatchery arid wild fishes that effect the hatchery generation have been well documented (Hynes et al. 1981, Krueger et al. 1981, Kincaid 1983, Allendorf and Ryman 1987, Kapuscinski and Jacobson 1987, Waples 1991). However, waiting for restoration of natural reproduction is a more dangerous risk because the entire population is threatened. The continued decline in population size risks additional loss of genetic variability and possible extinction of the population.

Many of the potentially detrimental effects associated with captive culture can be reduced significantly by incorporating simple precautions into the breeding plan (Hynes et al. 1981, Krueger et al. 1981, Kincaid 1983, Allendorf and Ryman 1987, Kapuscinski and Jacobson 1987). These precautions include (1) plant fish at the earliest possible life stage, (2) maintain fish at low rearing densities during culture, (3) maintain high numbers of brood fish (effective population numbers), (4) equalize the genetic contribution of all parental fish to the next generation, (5) capture brood fish from throughout the fishery and spawning season, (6) spawn all mature adults available, and (7) avoid selection of brood fish and progeny based on physical appearance and captive performance.

This breeding plan provides a systematic approach to preserve the Kootenai River white sturgeon gene pool, while management agencies work to restore river habitat conducive to natural spawning and larval survival. Until a breeding plan is initiated, however, the number of fish in this population will continue to decline. This plan guides management in the systematic collection and spawning of wild adults before they are lost from the breeding population. This approach attempts to preserve a greater portion of the available genetic variability than "doing nothing-while we wait" for restoration of natural spawning conditions.

NOTE: The captive breeding program outlined here should be discontinued when natural reproduction is re-established. If natural reproduction is not restored, however, the program must be continued every year for a minimum of one generation (a 20-year period) to restore the natural age structure. If the breeding plan is followed faithfully for the 20-year generation interval, it will yield a broodstock with an effective population size of approximately 200, or 22.7% of the current population.

OBJECTIVES

The objectives of the proposed breeding plan are as follows:

1. Describe a long-term breeding approach to preserve genetic variability.
2. Provide a multi-year breeding system to reestablish age structure.
3. Provide a breeding structure to create and maintain a “high” effective population size.
4. Describe “preservation stocking” methods to minimize potential detrimental effects of conventional supplemental stocking programs.
5. Describe small-lot cultural procedures to reduce the risk of detrimental genetic effects commonly associated with intensive hatchery production.
6. Describe a marking system to maintain family identity throughout the life cycle.

EFFECTIVE BREEDING POPULATION

The effective breeding number (N_e) for a population is the number of individuals in a random breeding population with an equal sex ratio, which would yield the same rate of inbreeding or genetic drift as the population beiig studied (Falconer 1981).

$$N_e = \frac{4 \times N_m \times N_F}{(N_m + N_F)}$$

This formula calculates the N_e (effective population size) for populations produced from random mating N_m male parents and N_f female parents. Ideally, N_e is calculated from counts of the actual number of parents that contribute progeny to the next broodstock generation. Because the actual number of individuals contributing progeny to the next generation and the number of progeny each contributes is unknown in most populations, the number of individuals that spawn and produce progeny is used in the calculation, i.e., the total number of fish spawned of each sex. For animal species with multi-year generation intervals, N_e is calculated using the sum of all males (NJ and females (NJ spawning each year for the number of years in the generation interval adjusted by any difference in sex ratio and the number of individuals that spawn more than once per generation. The generation interval is defined as the average age of females at first maturity, or about 20 years for the Kootenai River white sturgeon. The N_e will be the total of all spawners (different fish spawned) over the 20-year generation interval.

The situation assumed for the Kootenai River white'sturgeon population produced under the proposed captive culture program is that (1) each fish spawns only once per generation, (2) each individual contributes progeny to a single generation (i.e., generations do not overlap), and (3) each parent contributes an equal number of progeny to the next generation. While white sturgeon can (and do) spawn multiple times during their reproductive life, the above conservative assumptions are reasonable because (1) the actual spawning frequency of white sturgeon in the Kootenai River is unknown, (2) little successful reproduction has been documented in this population since 1974 (about one generation) to contribute a progeny generation, and (3) the proposed breeding plan limits, but does not eliminate, multi-year spawning of individual fish.

Ideally, all sexually mature individuals should be spawned to contribute progeny to the next generation, to ensure the total parental gene pool is transmitted to the progeny generation. In the situation where a natural population is perpetuated by randomly sampling the parental generation, the minimum recommended number of founder stock to ensure the genetic integrity of the gene pool is 100 to 200 fish (Allendorf and Phelps 1980, Hynes et al. 198 1, Krueger et al. 198 1, Kincaid 1983). In light of the threatened status of Kootenai River white sturgeon, a random sample of 200 fish (100 males and 100 females) should be spawned to contribute progeny to the next generation over the next 20 years. This works out to an average of 10 brood fish (total of males and females) per year, i.e., 10 different fish each year for 20 years. While the actual number in any given year may be more or less, the average of 10 needs to be achieved to minimize the risk of losing genetic variability. The annual N_e values, for different numbers of males and females available for mating, are shown in Table 1. The practice of stocking equal numbers of progeny from each family will maximize N_e by reducing variability of family size and will also minimize any effects of domestication (Ryman and Laikre 1990, Allendorf 1993).

The Kootenai River white sturgeon restoration program will undertake concurrent thrusts: (1) to obtain higher water flows in the river to re-establish natural spawning habitat, and (2) to initiate a captive culture program to preserve the existing genetic variation until natural spawning is restored. As a result, a constraint is placed on the captive culture program to ensure that at least 50% of mature females in any given year are retained in the fishery and allowed to spawn "naturally," if river conditions permit. Reports by Apperson and Anders (1990, 199 1) indicate 19-55 females are mature each year. Using the lower value, up to 9 females could be captured and spawned to produce fish for the culture program. To ensure that-mature fish are available to spawn (naturally) in the river when adequate spawning conditions are present, any fish (male or female) not required for the cultural program must be returned to the river before the start of the spawning season.

ANNUAL BREEDING AND CAPTIVE CULTURE PLAN

This breeding plan requires the systematic capture of sexually mature wild fish from staging areas in the Kootenai River. Captured fish will be held for 1 to 2 months until ready to spawn. At maturity, each female will be spawned and the eggs fertilized with milt from one male (see mating design options that follow) to form a family. The resulting families will be incubated separately. After recovery from the spawning operation, wild brood fish will be returned to the river at the point of capture. When a family is hatched and before the fry begin to feed, it will be divided randomly into two or more separate tanks for rearing to the target stocking age. Throughout the cultural operation, special care must be taken to ensure that positive family identity is maintained. When tanks become overcrowded, fish will be divided randomly (i.e., no selectionof fish except for gross abnormalities) into two tanks. When fish reach the target stocking age, equal numbers of fish from each family will be stocked into the river. Repeating the basic breeding plan each year over the entire generation interval will produce successive year classes to re-establish the natural age structure of the wild population. All fish that are surplus to stocking needs will be destroyed using approved euthanasia procedures.

NOTE: Surplus fish should not be retained in the program to avoid the temptation to plant (supplemental stocking) them, which is not desirable in programs designed to preserve the genetic variation of unique gene pools.

MATING DESIGN OPTIONS

The number of mature males and females captured from the fishery will vary from year to year, leading to the need for both single pair and half-sib family mating designs. Ideally, single pair matings (one male to one female) are preferred, with each fish used as a parent only once. However, in view of the difficulty in capturing sexually mature fish, the expectation that more males than females will be recovered, and the frequency of multiple recaptures of the same fish in successive years, the following rules for mating and handling fish will be followed.

1. When the number of spawning fish is 4 or more mating pairs (4 males and 4 females), mate 1 male to 1 female (using each fish as a parent in only 1 mating) to create totally unrelated families. Fish in excess of 8 pairs will be returned to the river and allowed to spawn naturally.
2. When there are 3 mature females in the captured broodstock, eggs from each female should be divided into 3 aliquots and mated to different males to form half-sib families for each female. Because males must not be used in more the 1 mating, a total of 9 males will be required. Males will be randomly assigned to the individual females. This will create a set of 3 half-sib families for each female, with

no relationship between female half-sib family sets. Males in excess of 9 will be released and allowed to spawn naturally.

3. When there are 2 mature females in the captured broodstock, eggs from each female should be divided into 4 aliquots and mated to different males to form half-sib families for each female. Because males must not be used in more than 1 mating, a total of 8 males will be required. Males will be randomly assigned to the individual females. This will create a set of 4 half-sib families for each female, with no relationship between female half-sib family sets. Males in excess of 8 will be released and allowed to spawn naturally.
4. When only 1 mature female is available, no lots will be spawned. All fish will be returned to the river and allowed to spawn naturally.
5. After a fish, male or female, has produced 1 progeny family, it should not be spawned again for at least 5 years. If the fish is recaptured during the 5-year period, it should be released and allowed to spawn naturally. After 5 years, a fish could be used to produce a second family if no other unused fish are available for spawning. No fish should be used more than twice in the culture program, except females mated to multiple males in items 2 and 3 above. This rule serves to limit and equalize the genetic contribution of individual parents to the progeny generation under the captive culture program. Its primary effect will be to limit repeated use of males captured each year because the reported spawning frequency is 2-4 years for males and 3-10 years for females (Conte 1988). Fish that mature multiple years during the next 20 years will have the opportunity to contribute to the fishery through the captive culture program and natural spawning.
6. All fish not already tagged will be PIT (passive integrated transponder) tagged as they are captured and a permanent record established. Data recorded will include the capture location and the length, weight, and breeding history of each fish.

RECORD SYSTEM

Breeding history, recapture frequency, and progeny production information from each brood fish is essential for management to know the genetic contribution to the succeeding generation and the ultimate success of the long-term genetic variability maintenance program. The record system must contain at least the following infornnation: (1) identity of individual brood fish, (2) progeny family identification, (3) progeny year-class identification, (4)number of progeny stocked per family, (5) survival of each family to maturity, and (6) contribution of each family to the next captive broodstock generation.

A tagging system (PIT tags) to provide positive identification of parental fish will be essential for development of breeding history information to allow biologists to limit the genetic contribution of individuals captured year after year. A marking system will also be essential to identify families and year classes for determination of post-stocking survival and subsequent genetic contribution to the next generation. Because PIT tags are expensive and too large for subyearling fish, they are not suitable for use on fall fingerlings. A multiple mark system, using a combination of coded-wire tags and scute removal (Rein et al. 1993), would provide positive identification of families, year-classes, and hatchery origin needed to accommodate a subyearling planting program. The coded-wire tag would identify that a fish was produced by a captive broodstock mating and would provide family and year-class information. Scute removal in specific locations would also provide a visual mark to identify the family and the year-class of all fish planted. When fish are recovered from the fishery at a later age, they would be identified by reading the scute record then PIT tagged to initiate the individual and family record. As fish are recaptured in the future, tag number, distinguishing mark, length, weight, recovery location, and recovery date will be recorded in the permanent record. Information gained from this program will allow managers to evaluate survival, growth, and reproduction on a family basis.

TARGET STOCKING NUMBER

The recruitment goal for each family in this program is "enough fish to produce 4 to 10 adults at 20 years of age." This number will allow the broodstock population to expand slowly with a "natural" variability in family contribution to the succeeding generation. The genetic contribution of each family will be limited by the number of fish planted, and each brood fish will be limited by the number of times its gametes are used in captive matings. Variation in the number of progeny contributed to the next broodstock generation will occur naturally because of differential survival resulting from natural selection and random chance after the fish are returned to the river. The primary difficulty in determining the number of fish to stock from each family is a lack of information on post-stocking survival of juvenile white sturgeon from age 0 to age 20. This lack of information prevents calculation of optimal stocking rates based on age at stocking. In addition, normal year-to-year environmental variation in precipitation, flooding, flow rates, temperature, predator populations, and food supply can create wide variation in annual and long-term survival.

A range of survival rates at successive life stages can be modeled, leading to very different optimum planting rates (Table 2). If fish are planted at age 1+ and have annual survival rates of 50% the first year, 60% the second, 70% the third, and 80% thereafter through the 18th year (age 20), a 1,000 fish plant will yield 7 brood fish at age 20 (Case 5, Table 2). Based on these assumptions, stocking 1,000 fish per family would produce the 4- 10 breeding adults desired in the next broodstock generation. Until better information is developed, a target of 1,000 yearling or 5,000 fall fingerlings (age, 3-6 months) should be planted per family. These numbers would be adjusted when recovery data from the initial plantings become available.

PRESERVATION STOCKING

The standard concept of supplemental stocking is that large numbers of fish are reared to the fingerling or yearling stage, then planted on top of a "natural" population to expand the production of that fishery. The goal of a supplemental stocking program is typically to expand the population or increase production of a fishery; little attention is given to preservation of the existing gene pool. The term "preservation stocking" is used here to indicate that preservation of genetic variability is the primary objective of the program; "slow" expansion of the population is a secondary goal. Undesirable effects commonly associated with supplemental stocking occur when the hatchery product (1) competes with wild fish for food and rearing space, resulting in reduced survival of the wild fish; (2) competes with wild fish for spawning habitat, resulting in reduced reproduction of the wild fish; and (3) interbreeds with wild fish, resulting in the introduction of hatchery-adapted genes, which dilute the genetic attributes and gene complexes that enhance "wild" survival, growth, and reproductive performance. This plan differs from "conventional" supplemental stocking in several ways. First, because the current broodstock has not reproduced successfully since 1974, there is no reproducing population of white sturgeon in the Kootenai River to compete and interbreed with fish planted under this plan. Second, the number of fish planted will be small compared with conventional supplemental stocking programs. The number of fish planted per family will be equalized at a level designed to produce only 2-5 times broodstock replacement numbers.

The objective of this plan is to preserve the existing gene pool; therefore, the number of fish planted will represent equal numbers from all available families and will be only enough to produce 4- 10 adults per family at maturity. As individual fish will be used as parents only once every 5 years, the likelihood of inbreeding in future generations will be reduced. Effects of preservation stocking, as outlined under this plan, do not pose a threat to the genetic composition of the existing gene pool. Conversely, this plan offers an approach for preserving the genetic variability remaining in this seriously threatened, declining white sturgeon population.

RECOMMENDATIONS FOR OTHER STEPS TO AID RESTORATION

During the initial stages of this program major efforts should be made to collect additional genetic information on the Kootenai River white sturgeon, to develop cultural technology to rear multiple small lots, and to develop nonsurgical spawning techniques.

1. Limited genetic baseline information (Setter and Brannon, 1992) and no breediig history are available on the Kootenai River White sturgeon. Because there is a high probability that actual effective population size is much less than indicated by the 1990 estimate of population size (880 individuals), a refined estimate of N_e would be valuable. The linkage disequilibrium method (Bartley et al. 1992) for N_e estimation would be appropriate and should be applied over the next 2 years. Non-lethal tissue samples (blood, muscle, and scute) could be taken from fish captured during routine netting operations for population assessment and broodstock capture. Tissue samples from each fish captured over a 2-year period (about 25-40 fish) would provide the information necessary to estimate N,. This information would help determine the urgency of implementing restoration efforts and provide guidance for adjustments to the proposed breeding plan.
2. The goal for the cultural operation will be an annual production of 8- 12 separate lots (families), each consisting of 5,000 fingerlings or 1,000 yearlings for stocking in the Kootenai River. This is new technology for many culturists and fishery biologists. Hatchery facilities will need to be redesigned and modified to accommodate these small groups effectively. Cultural practices and procedures will also need revision to provide reduced rearing densities, introduce special precautions to ensure absolute separation of family groups during culture, and implement tagging systems to give positive identification of individuals throughout the life cycle.
3. Techniques are needed for reliable, nonsurgical spawning of white sturgeon. Currently, most females are spawned by surgical removal of the eggs. The fish must then be held in the hatchery until the incision is healed. This means that while the female produced several hundred thousand eggs, only those retained for culture are available to the fishery; the remaining eggs are lost. Methods are needed to allow fish to be released after the initialspawning to complete spawning naturally in the river. If this is not possible, an alternative would be development of methodology to release fertilized eggs in “appropriate” spawning sites. A means is needed to ensure that gametes produced “in the river” can be used for both captive and natural spawning to provide maximum likelihood that the genetic variability of the Kootenai River white sturgeon will be preserved.

COMPARISON OF RESTORATION APPROACHES

Two approaches are proposed to restore white sturgeon in the Kootenai River. The first approach is to restore water flows in the Kootenai River, during the spawning season and developing fry period, to levels approaching those recorded in the early 1970's and known to support successful reproduction of white sturgeon. There is high expectation that increased water flow will support natural spawning, which will increase population number and begin to restore a natural age class structure. The advantage of this approach is that it is natural, and fish would not be subjected to hatchery culture, thereby avoiding potential domestication and exposure to disease organisms. The disadvantage is that population size would continue to decrease, with the associated loss of genetic variability, until the natural spawning habitat is restored. Despite high expectation, however, the possibility exists that increasing water flows alone may not restore natural spawning. If this were the case, and in light of the time needed for verification of successful spawning and recruitment, it could be several years before the true situation became known. During the period of verification, population size would continue to decline, and more of the older fish would become senile. The result would be continued disruption of age class structure, with additional missing year classes. If water flows to support natural spawning are not provided every year, the problem of verification of the true situation will be exacerbated because fewer juveniles would be available for capture.

The second approach, use of the captive breeding program described here, has the following advantages: (1) rebuilding the age structure would begin immediately, with a random portion of the mature broodfish each year contributing progeny to the next generation. All of these fish are currently lost to the fishery because of inadequate natural spawning habitat; (2) increased numbers of broodfish would contribute to the next generation before they were lost to senility or death; and (3) higher numbers of fish would survive to ages that could be successfully recruited into the population. Disadvantages include (1) increased exposure of broodfish and progeny to the cultural environment, i.e., artificial feed, tanks, handling, and diseases; (2) unavailability of captive fish to spawn naturally if suitable spawning conditions were present in the river; and (3) increased costs to produce and tag fish over several years.

The idea that these two approaches are incompatible is a misconception. There is no biological reason to prevent simultaneous implementation -of both approaches. Indeed, when the advantages and disadvantages of both approaches are considered in light of the current "threatened" status of the Kootenai River white sturgeon, simultaneous implementation of both approaches seems to offer the highest probability to protect and preserve the genetic variability of the Kootenai River white sturgeon.

The captive breeding plan allows management to begin the long-term process of re-establishing the natural age structure, using progeny from a random sample of the mature broodfish each year, before the population is reduced further. Captive breeding should be continued until evidence is available to show that natural reproduction is yielding adequate recruits to sustain the genetic variability of the population. Likewise, work to reestablish flow rates capable of supporting "quality" spawning and rearing habitat for all life stages should move forward as quickly as possible. Once natural habitat for sturgeon has been reestablished, the captive breeding program should be discontinued. The two approaches are supportive of each other and not incompatible when applied properly.

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Table 1. Effective population number based on the actual number of males and females used to produce the progeny generation. Identify the number of females in columns and the number of males in rows; the calculated effective breeding number for this combination can be read at the column and row intersection.

Number male parents	Number female parents											
	1	2	3	4	5	6	7	8	9	10	11	12
1	2.0	2.7	3.0	3.2	3.3	3.4	3.5	3.6	3.6	3.6	3.7	3.7
2	2.7	4.0	4.8	5.3	5.7	6.0	6.2	6.4	6.5	6.7	6.8	6.9
3	3.0	4.8	6.0	6.9	7.5	8.0	8.4	8.7	9.0	9.2	9.4	9.6
4	3.2	5.3	6.9	8.0	8.9	9.6	10.2	10.7	11.1	11.4	11.7	12.0
5	3.3	5.7	7.5	8.9	10.0	10.9	11.7	12.3	12.9	13.3	13.8	14.1
6	3.4	6.0	8.0	9.6	10.9	12.0	12.9	13.7	14.4	15.0	15.5	16.0
7	3.5	6.2	8.4	10.2	11.7	12.9	14.0	14.9	15.7	16.5	17.1	17.7
8	3.6	6.4	8.7	10.7	12.3	13.7	14.9	16.0	16.9	17.8	18.5	19.1
9	3.6	6.5	9.0	11.1	12.9	14.4	15.7	16.9	18.0	19.0	19.8	20.6
10	3.6	6.7	9.2	11.4	13.3	15.0	16.5	17.8	19.0	20.0	21.0	21.8
11	3.7	6.8	9.4	11.7	13.8	15.5	17.1	18.5	19.8	20.6	22.0	23.0
12	3.7	6.9	9.6	12.0	14.1	16.0	17.7	19.1	20.6	21.8	23.0	24.0

Table 2. Expected survival of white sturgeon for an 18-year period after planting, under different scenarios of annual survival rates. All examples are calculated on an initial stocking of 1,000 fish.

Years in river	Case 1 % surv.	Case 1 No. fish	Case 2 % surv.	Case 2 No. fish	Case 3 % surv.	Case 3 No. fish	Case 4 % surv.	Case 4 No. fish	Case 5 % surv.	Case 5 No. fish	Case 6 % surv.	Case 6 No. fish
1	0.5	500	0.5	500	0.5	500	0.50	500	0.5	500	0.50	500
2	0.5	250	0.6	300	0.6	300	0.60	300	0.6	300	0.60	300
3	0.5	125	0.6	180	0.7	210	0.70	210	0.7	210	0.70	210
4	0.5	63	0.6	108	0.7	147	0.75	158	0.8	160	0.80	168
5	0.5	31	0.6	65	0.7	103	0.75	118	0.8	134	0.85	143
6	0.5	16	0.6	39	0.7	72	0.75	89	0.8	108	0.85	121
7	0.5	8	0.6	23	0.7	50	0.75	66	0.8	86	0.85	103
8	0.5	4	0.6	14	0.7	35	0.75	50	0.8	69	0.85	88
9	0.5	2	0.6	8	0.7	25	0.75	37	0.8	55	0.85	75
10	0.5	1	0.6	5	0.7	17	0.75	28	0.8	44	0.85	63
11	0.5	0	0.6	3	0.7	12	0.75	21	0.8	35	0.85	54
12	0.5	0	0.6	2	0.7	9	0.75	16	0.8	28	0.85	46
13	0.5	0	0.6	1	0.7	6	0.75	12	0.8	23	0.85	39
14	0.5	0	0.6	1	0.7	4	0.75	9	0.8	18	0.85	33
15	0.5	0	0.6	0	0.7	3	0.75	'7	0.8	14	0.85	28
16	0.5	0	0.6	0	0.7	2	0.75	5	0.8	12	0.85	24
17	0.5	0	0.6	0	0.7	1	0.75	4	0.8	9	0.85	20
18	0.5	0	0.6	0	0.7	1	0.75	3	0.8	7	0.85	17

Years in river	Case 7 % surv.	Case 7 No. fish	Case 8 % surv.	Case 8 No. fish	Case 9 % surv.	Case 9 No. fish	Case 10 % surv.	Case 10 No. fish	Case 11 % surv.	Case 11 No. fish	Case 12 % surv.	Case 12 No. fish
1	0.6	600	0.3	300	0.3	300	0.40	400	0.2	200	0.20	200
2	0.8	480	0.4	120	0.4	120	0.60	240	0.4	80	0.50	100
3	0.9	432	0.8	96	0.9	108	0.75	180	0.6	48	0.60	60
4	0.9	389	0.8	77	0.9	97	0.75	135	0.8	38	0.70	42
5	0.9	350	0.8	61	0.9	88	0.75	101	0.9	35	0.80	34
6	0.9	315	0.8	49	0.9	79	0.75	76	0.9	31	0.80	27
7	0.9	283	0.8	39	0.9	71	0.75	57	0.9	28	0.85	23
8	0.9	255	0.8	32	0.9	64	0.75	43	0.9	25	0.85	19
9	0.9	230	0.8	25	0.9	57	0.75	32	0.9	23	0.90	18
10	0.9	207	0.8	20	0.9	52	0.75	24	0.9	20	0.90	16
11	0.9	186	0.8	16	0.9	47	0.75	18	0.9	18	0.95	15
12	0.9	167	0.8	13	0.9	42	0.75	14	0.9	17	0.95	14
13	0.9	151	0.8	10	0.9	38	0.75	10	0.9	15	0.95	14

Table 2. Continued.

Years in river	Case 7		Case a		Case 9		Case 10		Case 11		Case 12	
	% surv.	No. fish	% surv.	No. fish	% surv.	No. fish	% surv.	No. fish	% surv.	No. fish	% surv.	No. fish
14	0.9	136	0.8	a	0.9	34	0.75	a	0.9	13	0.95	13
15	0.9	122	0.8	7	0.9	31	0.75	6	0.9	12	0.95	12
16	0.9	110	0.8	5	0.9	28	0.75	4	0.9	11	0.95	12
17	0.9	99	0.8	4	0.9	25	0.75	3	0.9	10	0.95	11
18	0.9	a9	0.8	3	0.9	22	0.75	2	0.9	9	0.95	10

Table 3. Expected population size at 5 year intervals during the 250 year period from 1982 to 2340 are calculated, assuming an initial population of 880 and constant annual mortality rates of 1 to 10%. A 3.26% annual mortality rate (calculated mortality rate from 1982 and 1990 population estimates) is projected to show the current rate of population decline. Time to extinction was calculated for each mortality rate.

Count of years	Years	Survival calculation (3.26%)	Annual rate of loss from the population (%)									
			1	2	3	4	5	6	7	8	9	10
5	1995	745	837	795	756	718	681	646	612	580	549	520
10	2000	631	796	719	649	585	527	474	426	382	343	307
15	2005	535	757	650	557	477	408	348	296	252	214	181
20	2010	483	720	587	479	389	315	225	206	166	133	107
25	2015	383	684	531	411	317	244	187	143	109	a3	63
30	2020	325	651	480	353	259	la9	138	loo	72	52	37
35	2025	275	619	434	303	211	146	101	69	48	32	22
40	2030	233	589	392	260	172	113	74	48	31	20	13
45	2035	197	565	3.62	223	140	88	54	34	21	18	a
50	2040	167	532	320	192	114	68	40	23	14	5	5
55	2045	141	506	290	165	93	52	29	16	9		
60	2050	120	481	262	142	76	41	21	11	6		
65	2055	101	458	237	122	62	31	16	a	4		
70	2060	86	435	213	104	51	24	12	5			
75	2065	73	414	193	90	41	19	a	4			
80	2070	62	394	175	77	34	15	6				
a5	2075	52	375	158	66	27						
90	2080	44	356	143	57	22	17	5				
95	2085	37	339	129	49	la	5	2				
100	2090	32	322	117	42	15						
105	2095	27	306	105	36	12	4					
110	2100	23	291	95	31	10	3					
115	2105	19	277	86	26	8	2					
120	2110	16	263	78	23	7						
125	2115	14	251	70	20	5						
130	2120	12	238	64	17	4						

Table 3. Continued.

Count of years	Years	Survival calculation (3.26%)	Annual rate of loss from the population (%)									
			1	2	3	4	5	6	7	8	9	10
135	2125	10	227	58	14	4						
140	2130	a	215	52	12	3						
145	2135	7	205	47	11	2						
150	2140	6	195	43								
155	2145	5	185	38	9							
160	2150	4	176	35	8							
165	2155	4	168	31	6							
170	2160	3	159	28	5							
175	2165	3	152	26	4							
180	2170	2	144	23	4							
185	2175		137	21	3							
190	2180		130	19	3							
195	2185		124	17	2							
200	2190		118	15	2							
205	2195		112	14								
210	2200		107	13								
215	2205		101	11								
220	2210		96	10								
225	2215		92	9								
230	2220		a7	8								
235	2225		83	8								
240	2230		79	7								
245	2235		75	6								
250	2240		71	6								
Project years to extinction		191	643	324	209	155	123	102	87	76	67	60